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Jingu

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(54) **AMPLIFIER CIRCUIT**

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CPC ***H03F 1/3211*** (2013.01); ***H03F 1/302*** (2013.01); ***H03F 3/16*** (2013.01); ***H03F 3/193*** (2013.01); ***H03F 3/45*** (2013.01); ***H03F 3/45076*** (2013.01)

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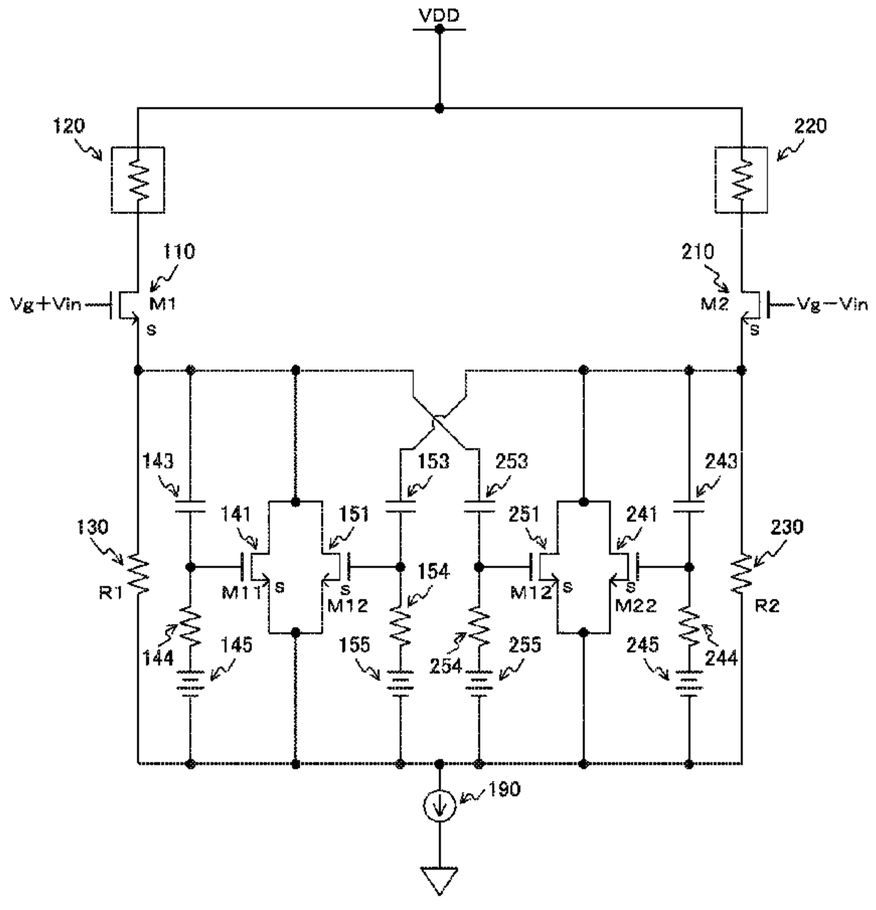
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(57) **ABSTRACT**

Linearity is improved in an amplifier circuit without lowering gain.
The amplifier circuit includes a transistor, a load, an impedance element, and a variable current source. The transistor amplifies an input signal. The load is connected between the transistor and a power supply. The impedance element is connected between the transistor and a ground terminal, and passes a direct current. The variable current source is connected to a connection part between the transistor and the impedance element, and supplies a current in accordance with a voltage of the connection part.

11 Claims, 11 Drawing Sheets



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H03F 1/30 (2006.01)
H03F 3/193 (2006.01)
H03F 3/16 (2006.01)

(58) **Field of Classification Search**
USPC 330/252–261, 296, 285
See application file for complete search history.

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FIG. 1

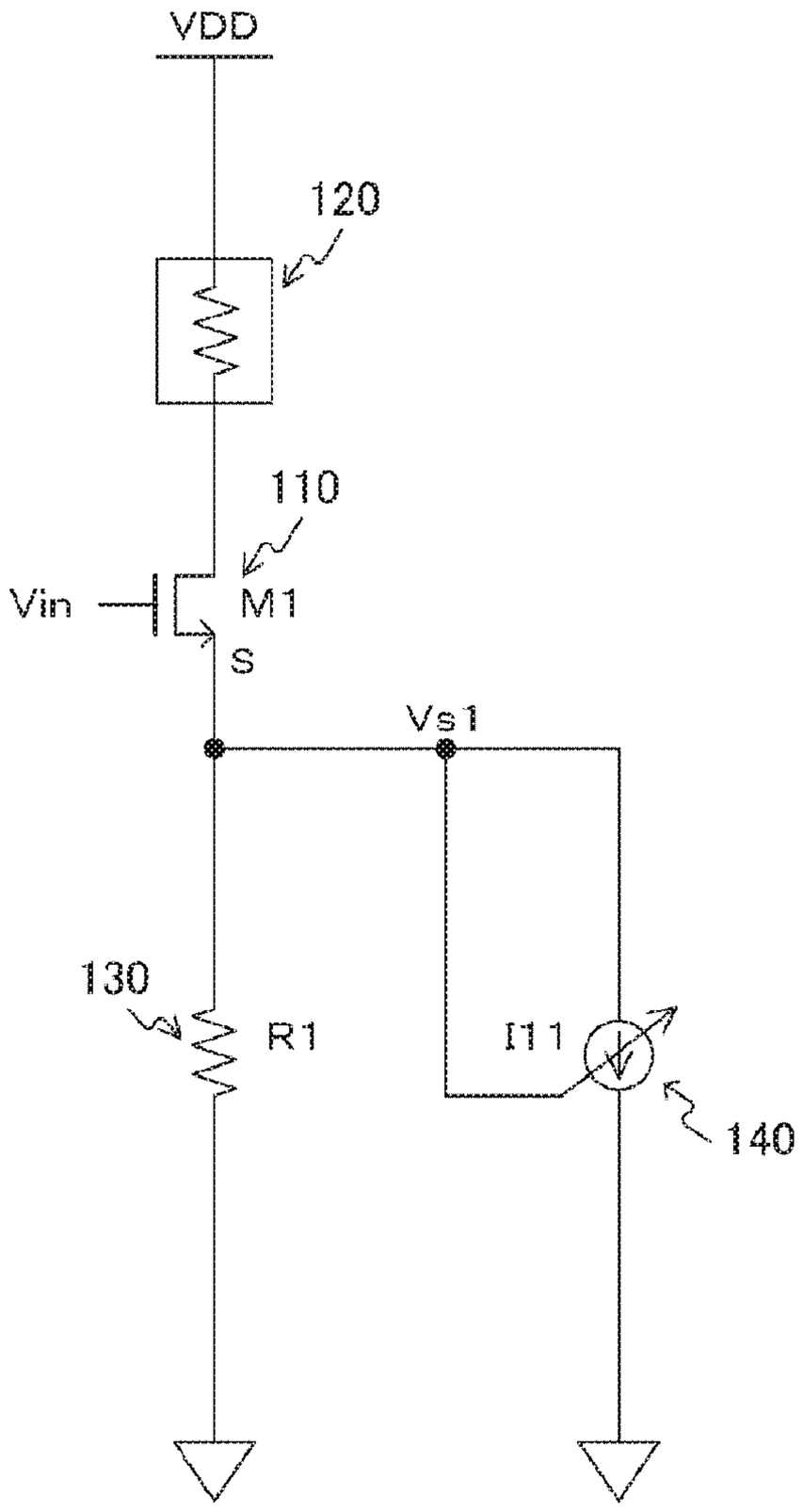


FIG. 2

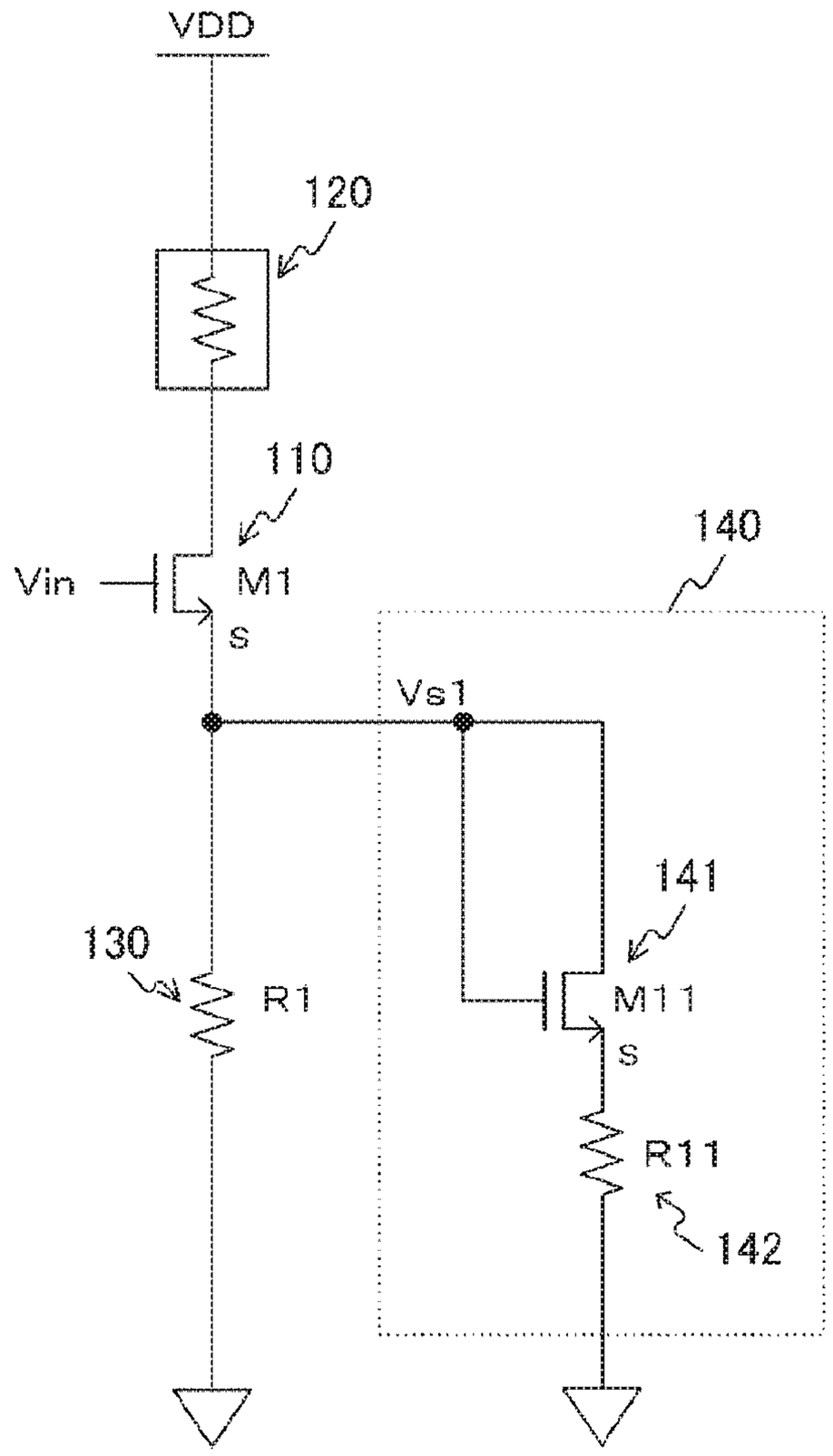
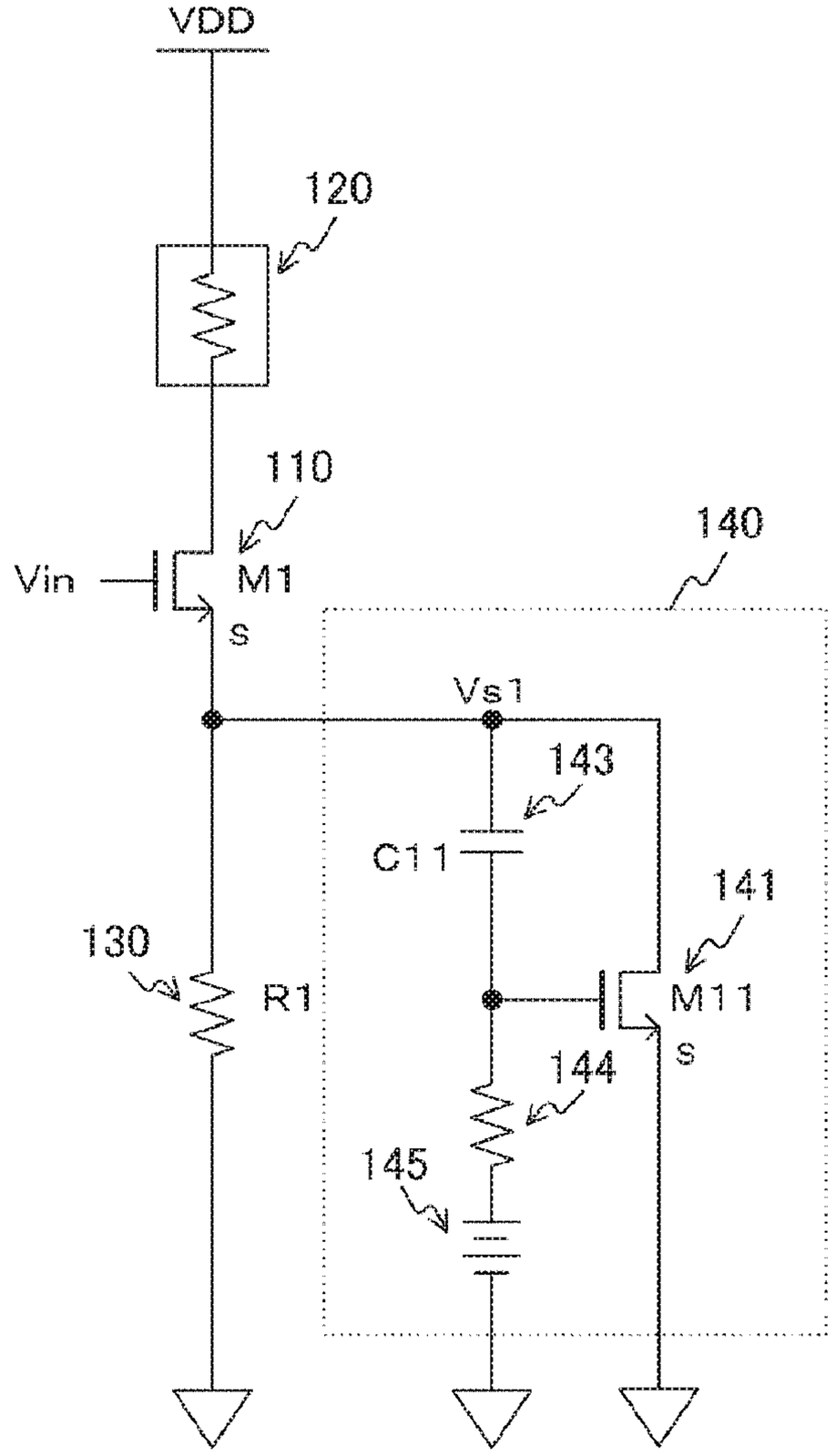


FIG. 3



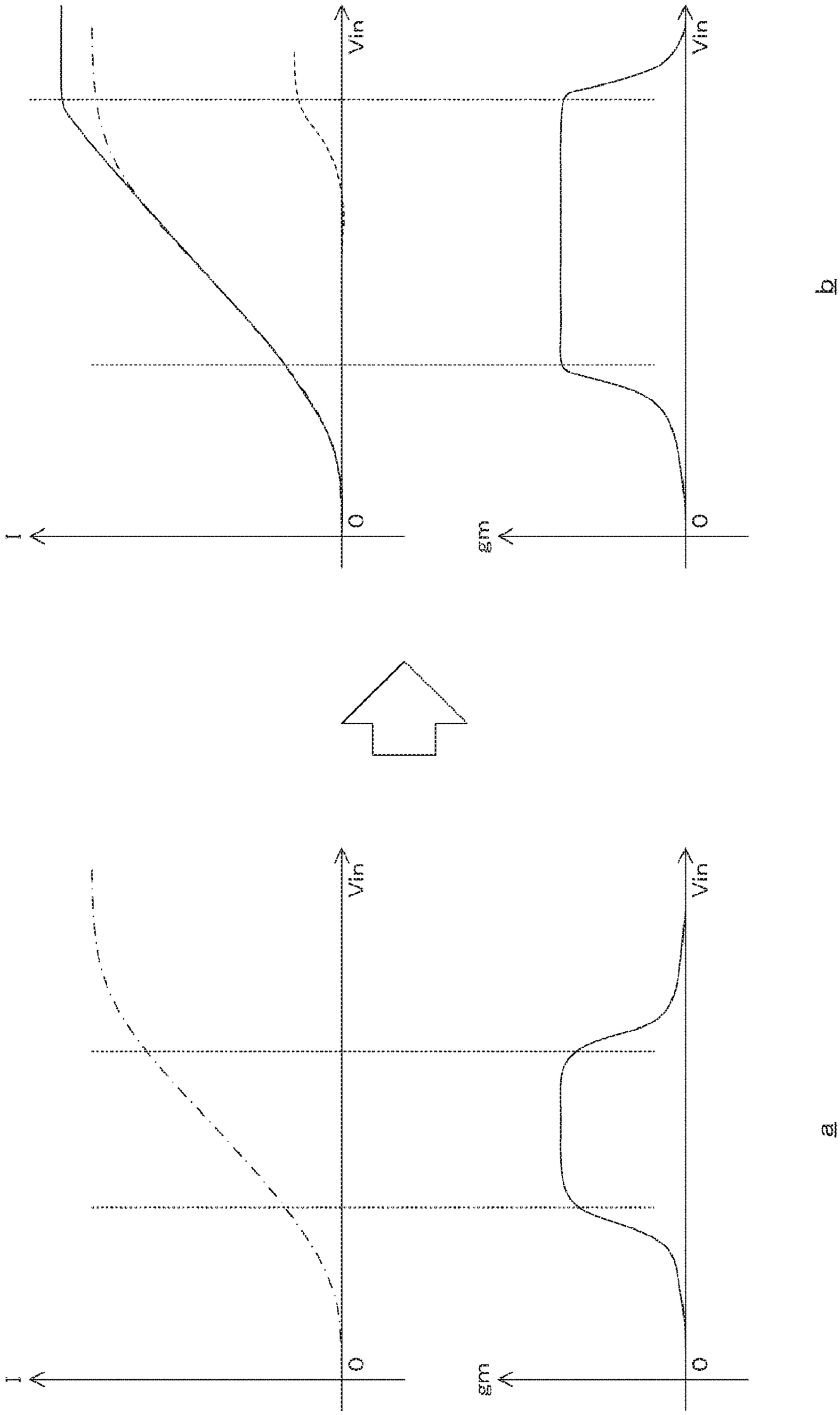


FIG. 4

FIG. 5

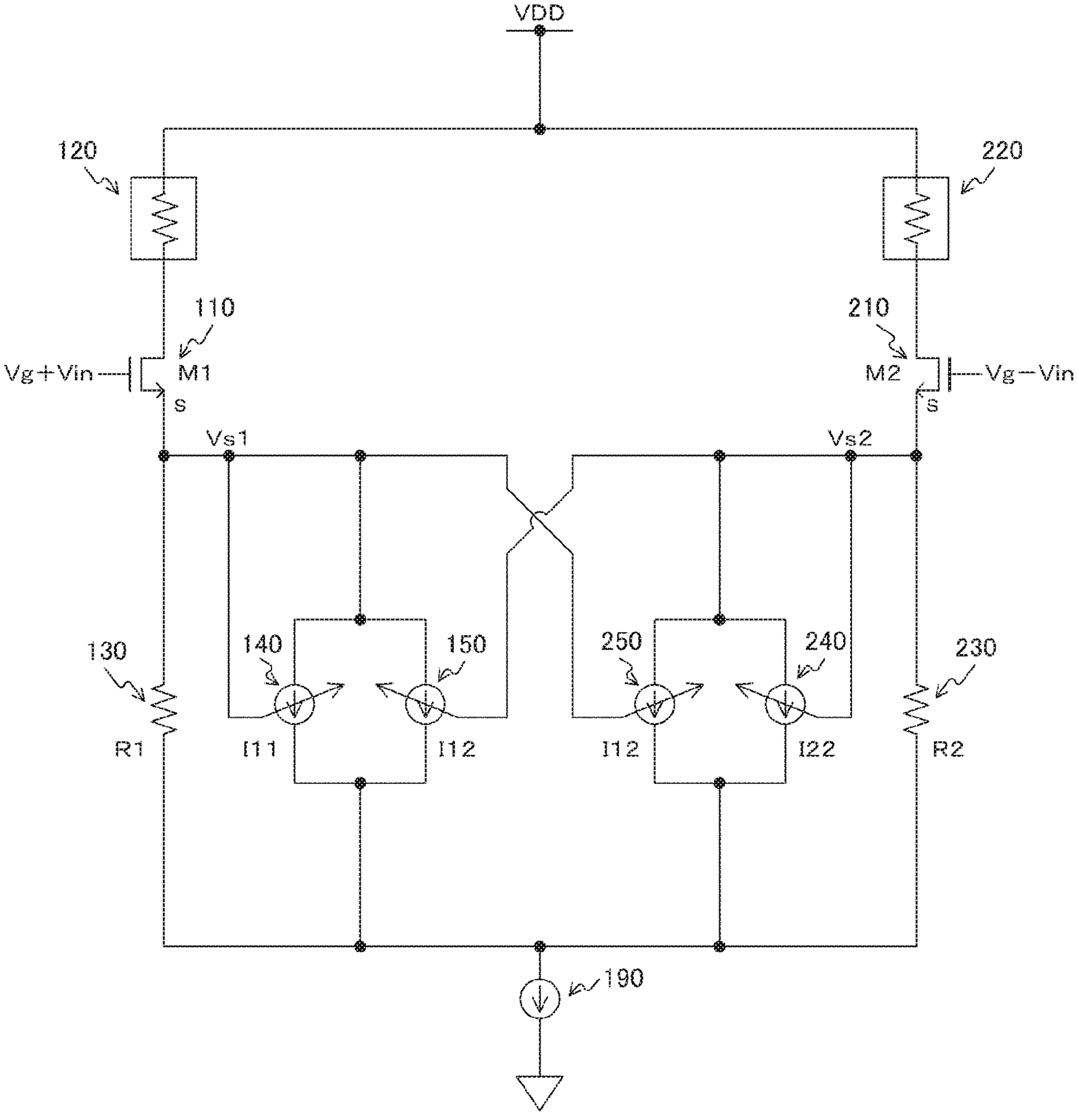

VDD
120
220
110
210
Vg+Vin
M1
S
M2
Vg−Vin
S
Vs1
Vs2
130
140
150
250
240
230
R1
I11
I12
I12
I22
R2
190

FIG. 6

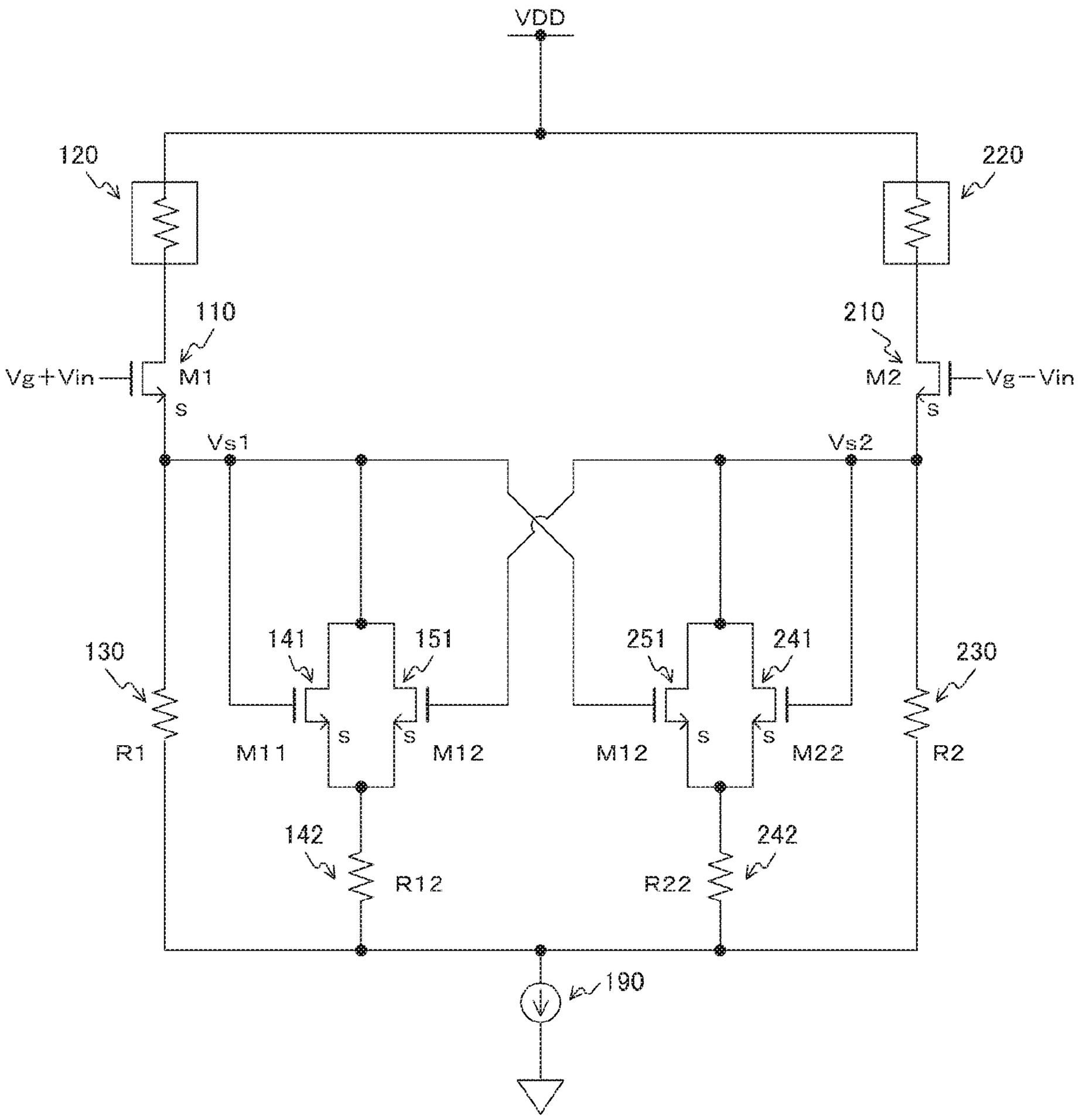
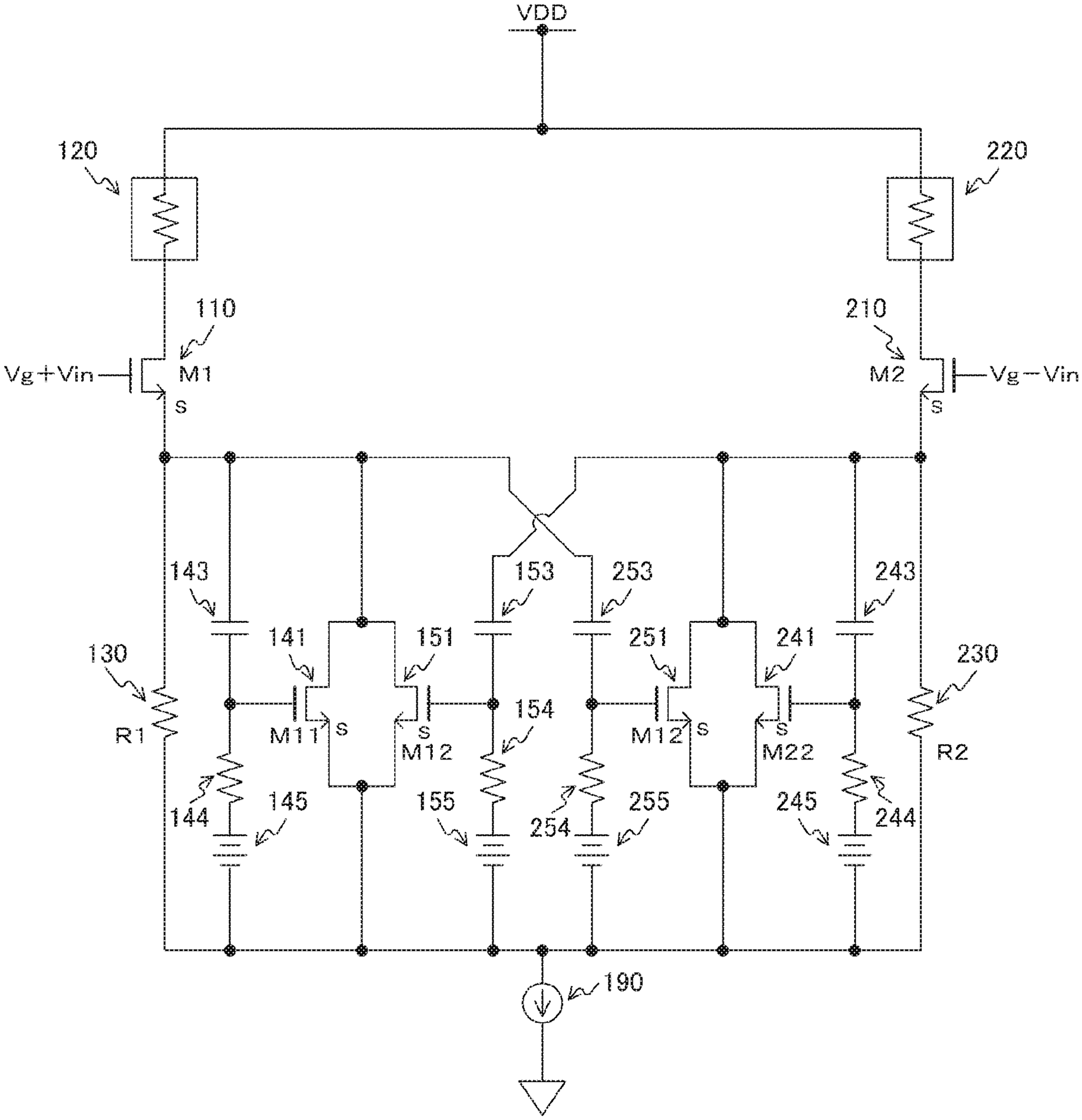

VDD
120
220
110
210
Vg+Vin
M1
S
M2
Vg−Vin
Vs1
Vs2
130
141
151
251
241
230
R1
M11
M12
M12
M22
R2
142
242
R12
R22
190

FIG. 7


VDD
120
220
110
210
Vg+Vin
M1
S
M2
Vg−Vin
143
153
253
243
141
151
251
241
130
230
154
R1
M11
M12
M12
M22
R2
144
145
155
254
255
245
244
190

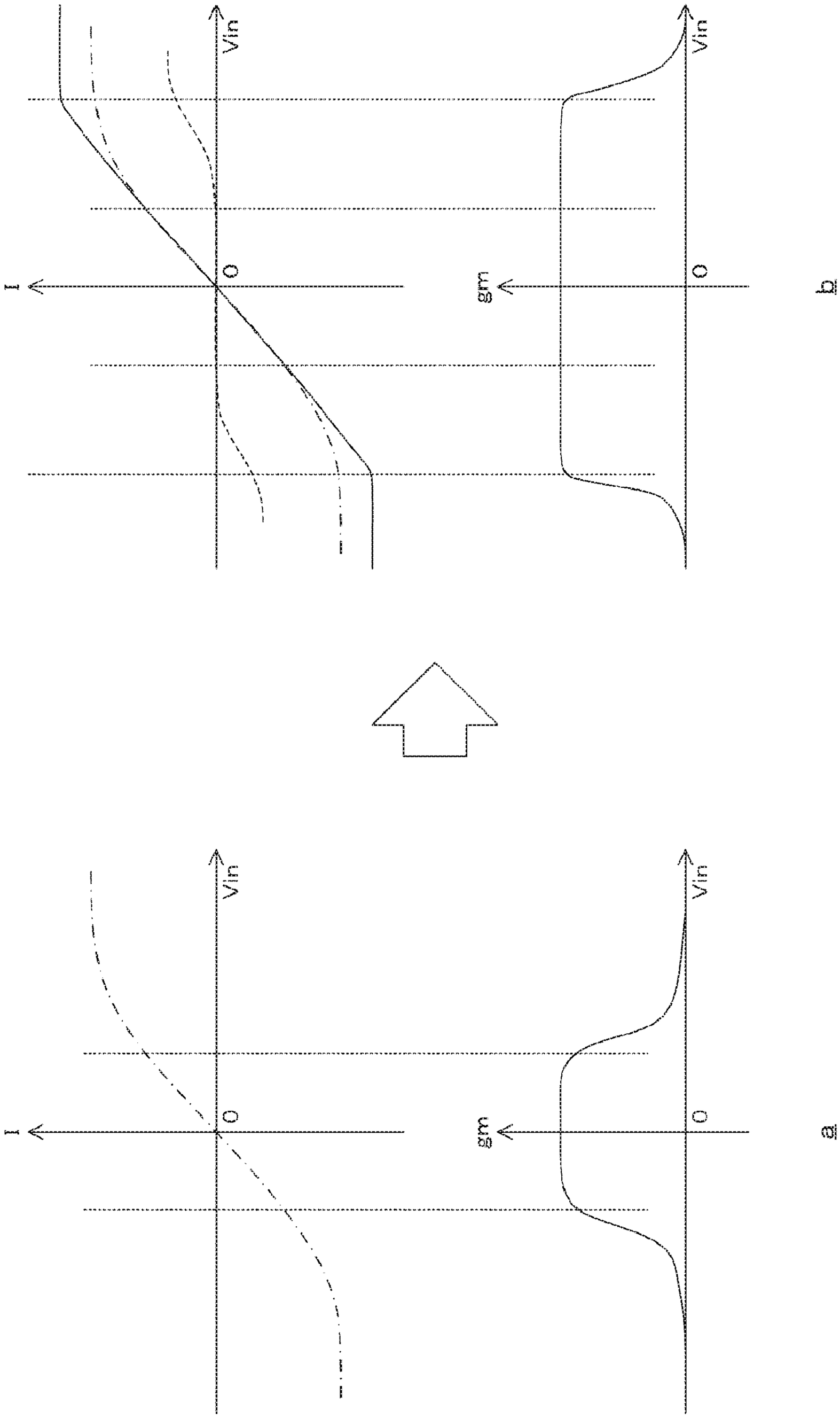


FIG. 8

FIG. 9

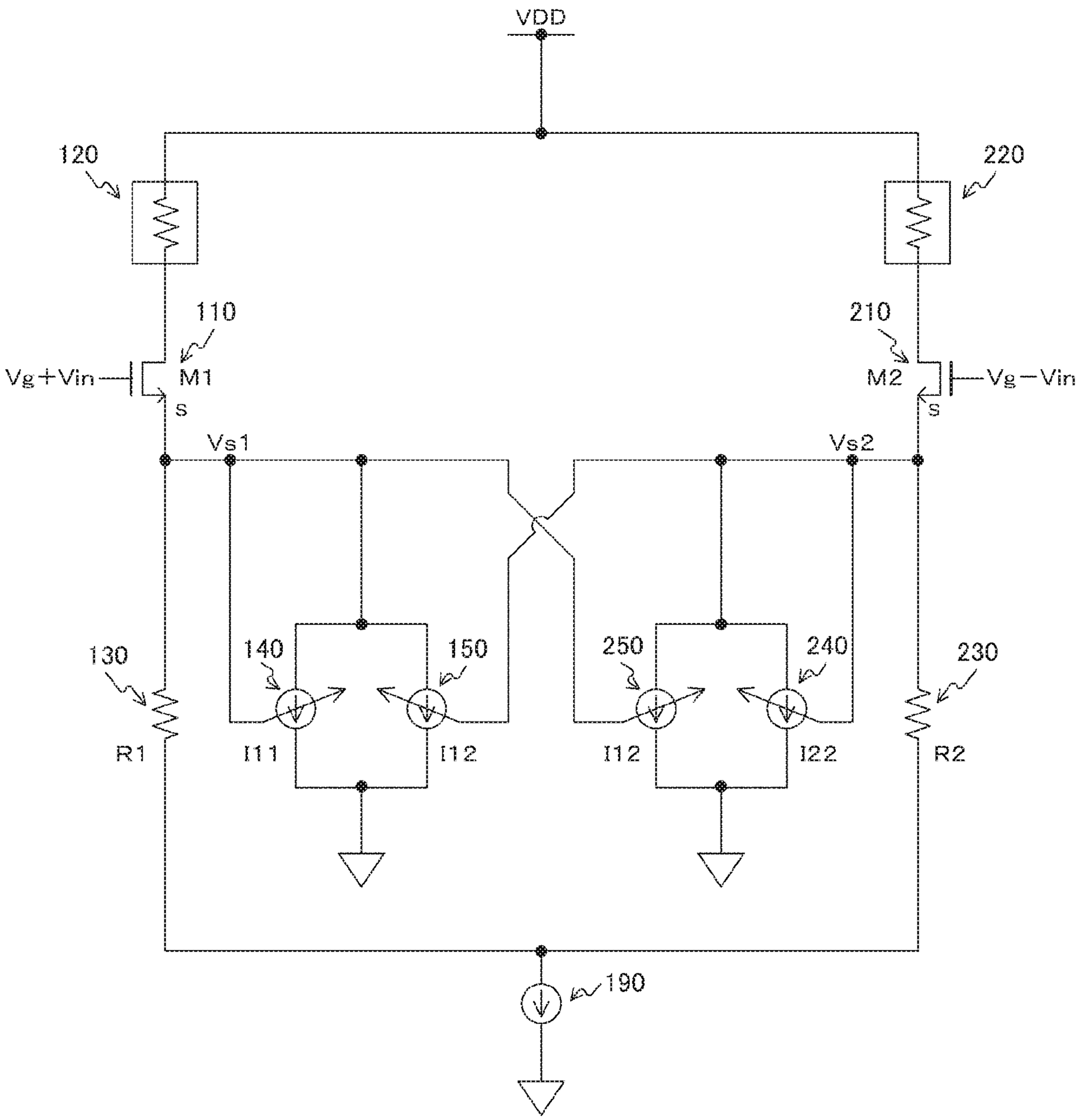

VDD
120
220
110
210
Vg+Vin
M1
S
M2
Vg−Vin
S
Vs1
Vs2
130
140
150
250
240
230
R1
I11
I12
I12
I22
R2
190

FIG. 10

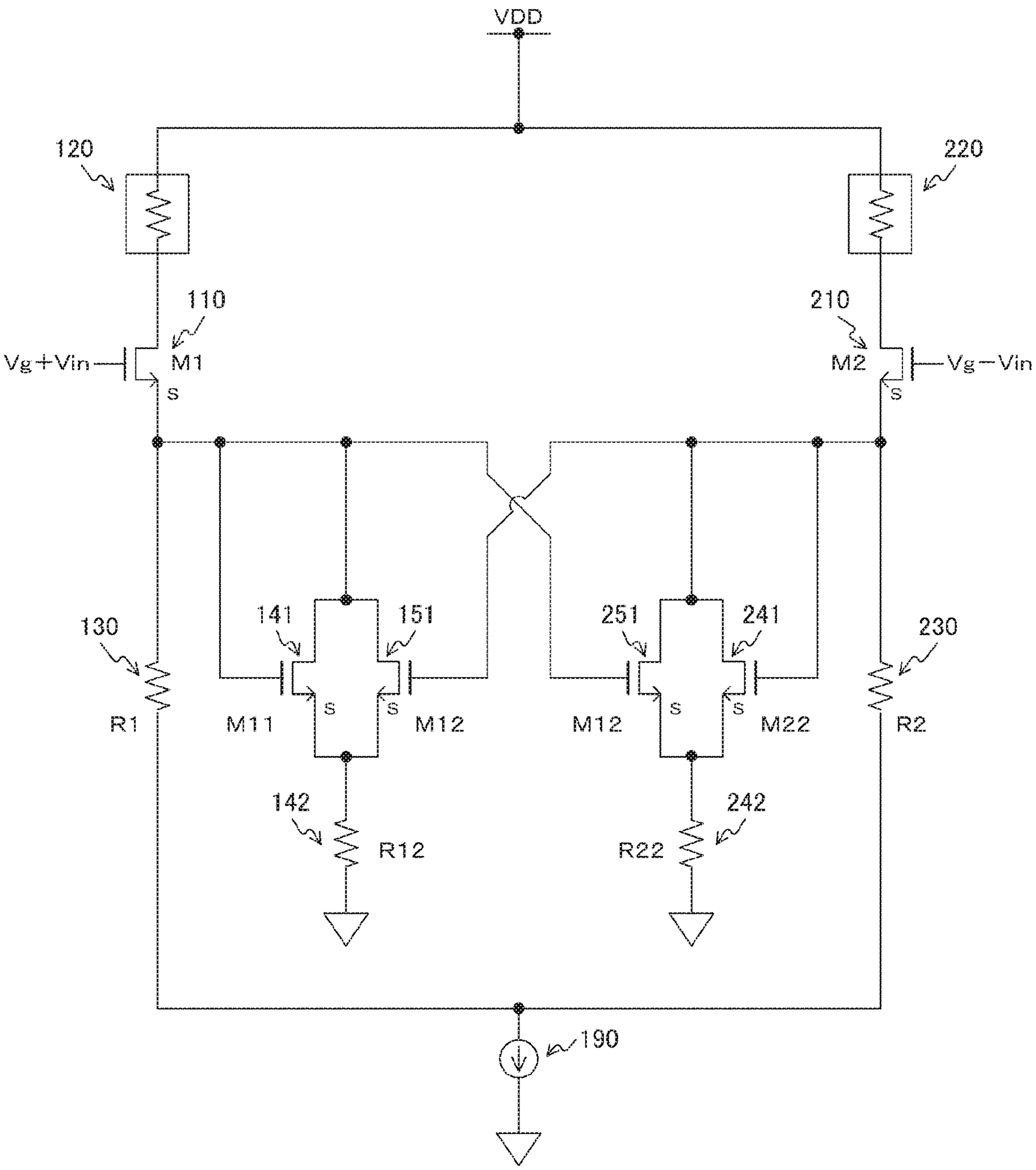
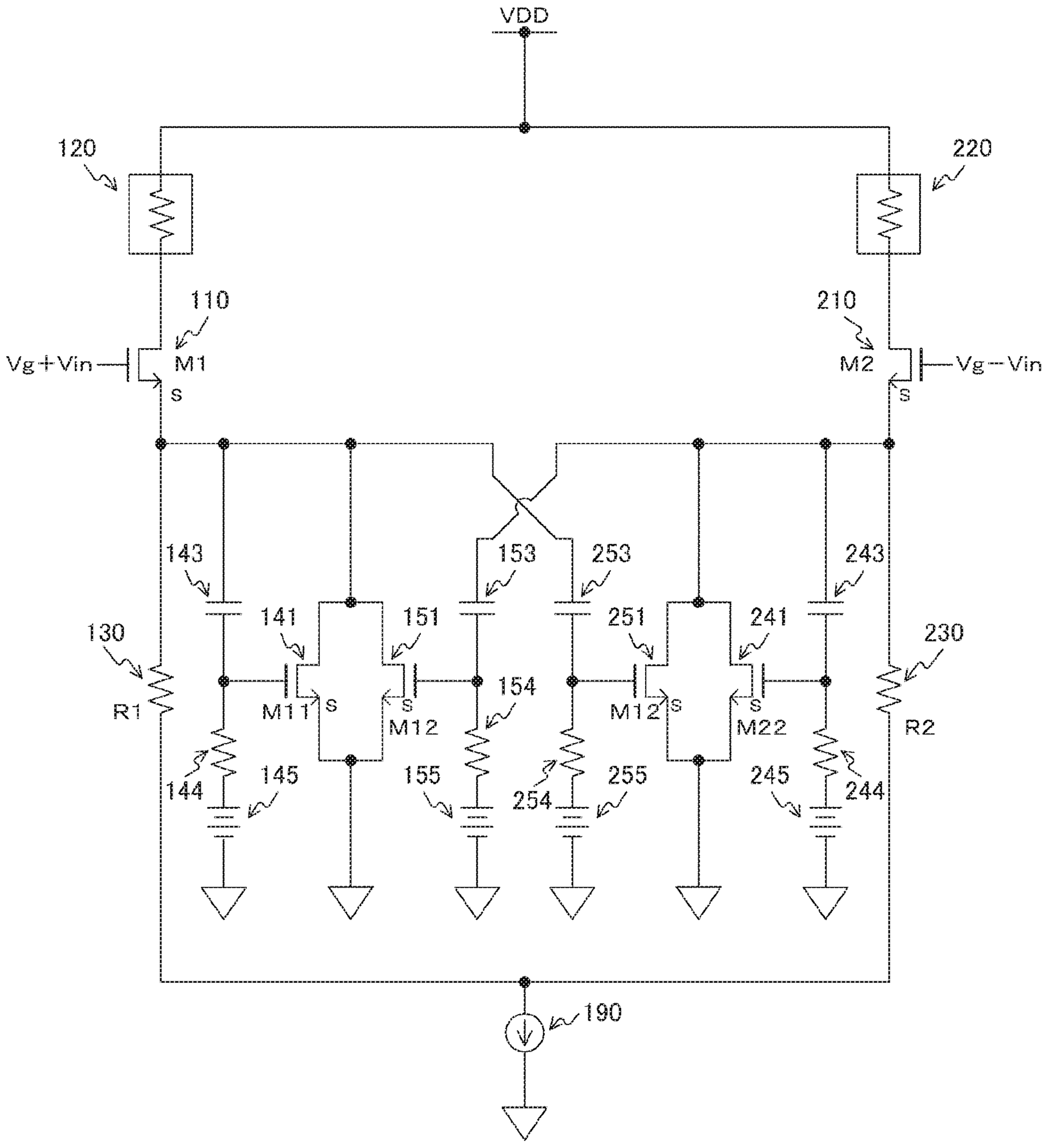

VDD
120
220
110
210
Vg+Vin
M1
S
M2
Vg−Vin
130
141
151
251
241
230
R1
M11
M12
M12
M22
R2
142
242
R12
R22
190

FIG. 11


VDD
120
220
110
210
Vg+Vin
M1
S
M2
Vg−Vin
143
153
253
243
141
151
251
241
130
230
R1
M11
M12
M12
M22
R2
154
144
145
155
254
255
245
244
190

AMPLIFIER CIRCUIT

TECHNICAL FIELD

The present technology relates to an amplifier circuit. Specifically, the present technology relates to an amplifier circuit in which an impedance element for passing a direct current, such as a resistor, is connected to a ground terminal of a transistor.

BACKGROUND ART

In an amplifier circuit, it is preferable that a range in which an output signal is linearly amplified (has linearity) is wide relative to an input signal. Conventionally, in a differential amplifier, for example, a circuit has been proposed in which cross-coupled transistors are inserted to subtract and combine a drain current (for example, see Patent Document 1). In this conventional technology, linearity is improved by performing subtraction to form a flat region because of a characteristic of a transconductance.

CITATION LIST

Patent Document

Patent Document 1: JP H06-026290 B2

SUMMARY OF THE INVENTION

Problems to be Solved by the Invention

In the above-described conventional technology, the cross-coupled transistors are used to subtract and combine a drain current to form a flat region in the characteristic of a transconductance, thereby improving linearity. However, in this conventional technology, there is a side effect that gain is lowered because a current is subtracted. In addition, there is a problem that power consumption increases due to a bias current of the cross-coupled transistors.

The present technology is developed in view of such a situation, and an object of the present technology is to improve linearity without lowering gain in an amplifier circuit.

Solutions to Problems

The present technology has been made to solve the above problems, and a first aspect of the present technology is an amplifier circuit including: a transistor that amplifies an input signal; a load connected between the transistor and a power supply; an impedance element that is connected between the transistor and a ground terminal and passes a direct current; and a variable current source that is connected to a connection part between the transistor and the impedance element and supplies a current in accordance with a voltage of the connection part. This configuration produces an effect of supplementing characteristics of the transistor by supplying the current in accordance with the voltage of the connection part.

In addition, in the first aspect, the transistor may be a MOS transistor that amplifies the input signal input to a gate and outputs the amplified input signal to a drain, the load may be connected to the drain of the transistor, the impedance element may be connected to a source of the transistor, and the variable current source may supply a current in accordance with a source voltage of the transistor to the source of the transistor. This configuration produces an effect of supplementing characteristics of the MOS transistor by supplying the current in accordance with the source voltage.

In addition, in the first aspect, the variable current source may include: an additional transistor having a gate and a drain connected to the connection part; and a resistor connected between a source of the additional transistor and the ground terminal.

In addition, in the first aspect, the variable current source may include: an additional transistor having a drain connected to the connection part; a capacitor connected between the connection part and a gate of the additional transistor; a resistor having one end connected to the gate of the additional transistor; and a bias voltage source connected between another end of the resistor and the ground terminal.

In addition, in the first aspect, the variable current source may supply the current in accordance with the voltage of the connection part in a region where a current supplied by the transistor starts to saturate relative to the input signal. This configuration produces an effect of supplementing, by supplying the current in accordance with the voltage of the connection part, characteristics of the transistor in the region where the current supplied by the transistor starts to saturate.

In addition, in the first aspect, the impedance element may be a resistance element or an inductor element. In addition, in the first aspect, the load may be a resistance element.

In addition, a second aspect of the present technology is an amplifier circuit including: first and second transistors that amplify differential input signals; first and second loads respectively connected between the first and second transistors and a power supply; a current source having one end connected to a ground terminal; first and second impedance elements that are respectively connected between the first and second transistors and another end of the current source and pass a direct current; a first variable current source that has one end connected to a first connection part between the first transistor and the first impedance element and supplies a current in accordance with a voltage of the first connection part; a second variable current source that has one end connected to a second connection part between the second transistor and the second impedance element and supplies a current in accordance with a voltage of the second connection part; a third variable current source that has one end connected to the first connection part and supplies a current in accordance with the voltage of the second connection part; and a fourth variable current source that has one end connected to the second connection part and supplies a current in accordance with the voltage of the first connection part. This configuration produces an effect of supplementing characteristics of the transistor by supplying the current in accordance with the voltage of each connection part of the cross-coupled transistors.

In addition, in the second aspect, each of the first to fourth variable current sources may have another end connected to the another end of the current source. In this case, each of the first to fourth variable current sources may include: an additional transistor having a gate and a drain connected to the connection part; and a resistor connected between a source of the additional transistor and the another end of the current source. In addition, each of the first to fourth variable current sources may include: an additional transistor having a drain connected to the connection part; a capacitor connected between the connection part and a gate of the additional transistor; a resistor having one end connected to the gate of the additional transistor; and a power supply

connected between another end of the resistor and the another end of the current source.

In addition, in the second aspect, each of the first to fourth variable current sources may have another end connected to the ground terminal. In this case, each of the first to fourth variable current sources may include: an additional transistor having a gate and a drain connected to the connection part; and a resistor connected between a source of the additional transistor and the ground terminal. In addition, each of the first to fourth variable current sources may include: an additional transistor having a drain connected to the connection part; a capacitor connected between the connection part and a gate of the additional transistor; a resistor having one end connected to the gate of the additional transistor; and a power supply connected between another end of the resistor and the ground terminal.

Effects of the Invention

According to the present technology, it is possible to obtain an excellent effect that linearity can be improved without lowering gain in an amplifier Note that effects described herein are not necessarily limitative, and any of the effects described in the present disclosure may be obtained.

BRIEF DESCRIPTION OF DRAWINGS

FIG. **1** is a diagram illustrating a circuit configuration example of a source degeneration amplifier according to a first embodiment of the present technology.

FIG. **2** is a diagram illustrating a first specific example of a variable current source **140** in the source degeneration amplifier according to the first embodiment of the present technology.

FIG. **3** is a diagram illustrating a second specific example of the variable current source **140** in the source degeneration amplifier according to the first embodiment of the present technology.

FIG. **4** is a diagram illustrating examples of current characteristics of a transistor **110** according to the first embodiment of the present technology.

FIG. **5** is a diagram illustrating a circuit configuration example of a differential amplifier according to a second embodiment of the present technology.

FIG. **6** is a diagram illustrating a first specific example of variable current sources **140**, **150**, **240**, and **250** in the differential amplifier according to the second embodiment of the present technology.

FIG. **7** is a diagram illustrating a second specific example of the variable current sources **140**, **150**, **240**, and **250** in the differential amplifier according to the second embodiment of the present technology.

FIG. **8** is a diagram illustrating examples of current characteristics of a transistor **110** according to the second embodiment of the present technology.

FIG. **9** is a diagram illustrating a modification of the differential amplifier according to the second embodiment of the present technology.

FIG. **10** is a diagram illustrating a first specific example of the variable current sources **140**, **150**, **240**, and **250** in the modification of the differential amplifier according to the second embodiment of the present technology.

FIG. **11** is a diagram illustrating a second specific example of the variable current sources **140**, **150**, **240**, and **250** in the modification of the differential amplifier according to the second embodiment of the present technology.

MODE FOR CARRYING OUT THE INVENTION

Hereinafter, a mode for carrying out the present technology (hereinafter referred to as an embodiment) will be described. The description will be given in the following order.

1. First Embodiment (Example of Source Degeneration Amplifier)
2. Second Embodiment (Example of Differential Amplifier)
3. Modification

1. First Embodiment

[Circuit Configuration of Source Degeneration Amplifier]

FIG. **1** is a diagram illustrating a circuit configuration example of a source degeneration amplifier according to a first embodiment of the present technology.

The source degeneration amplifier is an amplifier circuit that amplifies an input voltage Vin. The source degeneration amplifier includes a transistor **110** (M**1**), a load resistor **120**, a degeneration resistor **130** (R**1**), and a variable current source **140** (I**11**).

The transistor **110** is a metal-oxide-semiconductor (MOS) transistor. The input voltage Vin is input to a gate of the transistor **110**. A drain of the transistor **110** is connected to a power supply VDD via the load resistor **120**. The drain of the transistor **110** serves as an output of the source degeneration amplifier. Note that, although an example using the MOS transistor is described here, the present technology can also be applied to a bipolar transistor. In addition, although an example in which the load resistor **120** is connected to the drain of the transistor **110** is described, an inductor element may be used as a load instead of the load resistor **120**.

In addition, the degeneration resistor **130** is connected to a source of the transistor **110**. The degeneration resistor **130** is an impedance element that generates a voltage proportional to the input voltage Vin to the gate of the transistor **110**, and is used to reduce distortion of gain (gain) as the amplifier circuit. It is known that the degeneration resistor **130** has a characteristic of lowering a transconductance and increasing an output resistance.

Note that, in a case where a high frequency operation is assumed, an inductor element (coil) may be provided instead of the degeneration resistor **130** serving as a resistance element. Although a loss occurs in the resistance element, such a loss can be avoided in the inductor element. On the other hand, although an impedance changes in the inductor element depending on a frequency, a broadband characteristic can be obtained in the resistance element independent of a frequency. Thus, it is desirable to appropriately select, as the impedance element for passing a direct current, the resistance element or the inductor element. In addition, the resistance element and the inductor element may be connected in parallel.

The variable current source **140** is a variable current source that is connected to the source of the transistor **110** and supplies a current in accordance with a source voltage Vs**1** to the transistor **110**. That is, the current supplied from the variable current source **140** is controlled by the source voltage Vs**1** of the transistor **110**.

Note that the load resistor **120** is an example of a load described in the claims. In addition, the degeneration resistor **130** is an example of an impedance element described in the claims.

FIG. **2** is a diagram illustrating a first specific example of the variable current source **140** in the source degeneration amplifier according to the first embodiment of the present technology.

The first specific example of the variable current source **140** includes a transistor **141** (M**11**) and a resistor **142** (R**11**). A gate and a drain of the transistor **141** are connected to the source of the transistor **110**. In addition, the resistor **142** is connected to a source of the transistor **141**. Note that the transistor **141** is an example of an additional transistor described in the claims.

A source voltage of the transistor **110** is input to the gate of the transistor **141**. A source voltage of the transistor **141** is a voltage of the resistor **142**. That is, the source voltage of the transistor **141** is at a ground level in a state where no current flows through the transistor **141**. Then, when a current flows through the transistor **141**, a voltage having a value obtained by multiplying the current by a resistance value R**11** of the resistor **142** serves as the source voltage of the transistor **141**. As a result, a current in accordance with a gate-source voltage of the transistor **141** flows to the drain of the transistor **141** and is supplied to the transistor **110**.

In this way, in the first specific example, a threshold voltage is adjusted by connecting the resistor **142** to the source of the transistor **141**.

FIG. **3** is a diagram illustrating a second specific example of the variable current source **140** in the source degeneration amplifier according to the first embodiment of the present technology.

The second specific example of the variable current source **140** includes the transistor **141** (M**11**), a capacitor **143** (C**11**), a resistor **144**, and a bias voltage source **145**. The drain of the transistor **141** is connected to the source of the transistor **110**. In addition, the gate of the transistor **141** is connected to the source of the transistor **110** via the capacitor **143**. In addition, the gate of the transistor **141** is connected to the bias voltage source **145** via the resistor **144**.

A class B or class C bias voltage is applied to the gate of the transistor **141** by the bias voltage source **145**, and when a large signal is input, a current starts to flow through the gate. In addition, a direct current component of a signal input to the gate of the transistor **141** is cut by the capacitor **143**. As a result, a current in accordance with a gate-source voltage of the transistor **141** flows to the drain of the transistor **141** and is supplied to the transistor **110**.

In this way, in the second specific example, a threshold voltage is adjusted by connecting the bias voltage source **145** to the gate of the transistor **141** and applying a class B or class C bias voltage to the gate. Note that the resistor **144** connected to the gate of the transistor **141** has a high resistance and does not contribute to the adjustment of the threshold voltage.

[Current Characteristics of Transistor]

FIG. **4** is a diagram illustrating examples of current characteristics of the transistor **110** according to the first embodiment of the present technology.

In FIG. **4**, a indicates a current characteristic of the transistor **110** in a case where the variable current source **140** is not provided. When the input voltage Vin is increased, a current I driven by the transistor **110** saturates and linearity deteriorates. Thus, in this embodiment, the saturation of the current characteristic is suppressed by connecting the variable current source **140** controlled by the source voltage Vs**1** to the source of the transistor **110**. When a current of the transistor **110** increases, the source voltage Vs**1** increases. The variable current source **140** is set to start flowing a current when the source voltage Vs**1** exceeds a certain threshold.

In FIG. **4**, b indicates a current characteristic of the transistor **110** in a case where the variable current source **140** is provided. An alternate long and short dash line indicates a current driven by the transistor **110** in the case of a of FIG. **4** where the variable current source **140** is not provided. In addition, a dotted line indicates a current driven by the variable current source **140**. Thus, in the case where the variable current source **140** is provided, both currents are added, and a current flowing through the transistor **110** is as indicated by a solid line.

Here, a transconductance gm is indicated in order to examine linearity of the current characteristics. The transconductance gm is a differential value of a current, and it is indicated that a voltage-current characteristic is linear in a region where the transconductance gm shows a constant value. In addition, when the transconductance gm is high, it is indicated that a voltage-current slope becomes steep and gain is high.

In the case where the variable current source **140** is provided, even if the input voltage Vin is increased, a current does not saturate until the input voltage Vin reaches a certain level, compared with the case where the variable current source **140** is not provided. That is, it can be seen that a linear region in which a waveform of the transconductance gm is flat expands by causing the current of the variable current source **140** to start flowing with the current saturation of the transistor **110**. That is, it is possible to increase a region that is linearly driven without reducing gain as an amplifier circuit.

A current to be flown by the variable current source **140** is determined by a manner of saturation of a current driven only by the transistor **110**. In an actual design, conditions such as a capability of a transistor used and a range of a voltage used are different. Thus, design options can be expanded by applying this embodiment.

As described above, according to the first embodiment of the present technology, it is possible to expand a region that is linearly driven without lowering gain by connecting the variable current source **140** to the source of the transistor **110** in the source degeneration amplifier.

2. Second Embodiment

[Circuit Configuration of Differential Amplifier]

FIG. **5** is a diagram illustrating a circuit configuration example of a differential amplifier according to a second embodiment of the present technology.

The differential amplifier is an amplifier circuit that combines the source degeneration amplifiers according to the above-described first embodiment and causes the combined source degeneration amplifiers to perform a differential operation. That is, a voltage obtained by adding an input voltage Vin to a gate voltage Vg is applied to a positive side transistor **110**, and a voltage obtained by subtracting the input voltage Vin from the gate voltage Vg is applied to a negative side transistor **210**.

As in the above-described first embodiment, a load resistor **120**, a degeneration resistor **130**, and a variable current source **140** are connected to the positive side transistor **110**. In addition, a variable current source **150** (I**12**) is connected in parallel with the variable current source **140**. The variable current source **150** is connected to flow a current through a source of the transistor **110** similarly to the variable current source **140**, but is controlled by a source voltage Vs**2** of the

transistor **210**. That is, the variable current source **150** supplies a current in accordance with the source voltage Vs**2** of the transistor **210** to the source of the transistor **110**.

Similarly to the positive side transistor **110**, a load resistor **220**, a degeneration resistor **230**, and variable current sources **240** and **250** are connected to the negative side transistor **210**. The variable current source **250** is connected to flow a current through a source of the transistor **210** similarly to the variable current source **240**, but is controlled by a source voltage Vs**1** of the transistor **110**. That is, the variable current source **250** supplies a current in accordance with the source voltage Vs**1** of the transistor **110** to the source of the transistor **210**.

That is, the variable current sources **150** and **250** causes the transistors **110** and **210** to operate as cross-coupled transistors. As a result, since the transistor to which a signal in a reverse phase is input is driven, and a current is canceled, a transconductance gm is inversely subtracted and becomes a constant value, and thus linearity is improved.

In addition, in the differential amplifier according to the second embodiment, the degeneration resistors **130** and **230** and the variable current sources **140**, **150**, **240**, and **250** are connected to a current source **190**.

Note that the transistors **110** and **210** are examples of first and second transistors described in the claims. In addition, the load resistors **120** and **220** are examples of first and second loads described in the claims. In addition, the degeneration resistors **130** and **230** are examples of first and second impedance elements described in the claims. In addition, the variable current sources **140**, **240**, **150**, and **250** are examples of first to fourth variable current sources described in the claims.

FIG. **6** is a diagram illustrating a first specific example of the variable current sources **140**, **150**, **240**, and **250** in the differential amplifier according to the second embodiment of the present technology.

As in the above-described first embodiment, the first specific example of the second embodiment includes a transistor **141** and a resistor **142** as the variable current source **140**. In addition, as the variable current source **150**, a transistor **151** is connected in parallel with the transistor **141**. In addition, as the variable current source **240**, a transistor **241** and a resistor **242** are provided. In addition, as the variable current source **250**, a transistor **251** is connected in parallel with the transistor **241**.

Note that each of the transistors **141**, **151**, **241**, and **251** is an example of an additional transistor described in the claims.

FIG. **7** is a diagram illustrating a second specific example of the variable current sources **140**, **150**, **240**, and **250** in the differential amplifier according to the second embodiment of the present technology.

As in the above-described first embodiment, the second specific example of the second embodiment includes the transistor **141**, a capacitor **143**, a resistor **144**, and a bias voltage source **145** as the variable current source **140**. In addition, as the variable current source **150**, the transistor **151**, a capacitor **153**, a resistor **154**, and a bias voltage source **155** are provided. In addition, as the variable current source **240**, the transistor **241**, a capacitor **243**, a resistor **241**, and a bias voltage source **245** are provided. In addition, as the variable current source **250**, the transistor **251**, a capacitor **253**, a resistor **254**, and a bias voltage source **255** are provided.

[Current Characteristics of Transistor]

FIG. **8** is a diagram illustrating examples of current characteristics of the transistor **110** according to the second embodiment of the present technology.

In FIG. **8**, a indicates a current characteristic of the transistor **110** in a case where the variable current sources **140** and **150** are not provided. When the input voltage Vin is away from 0 V, a current saturates and linearity deteriorates. The saturation of the current characteristic suppressed by connecting the variable current source **140** controlled by the source voltage Vs**1** and the variable current source **150** controlled by the source voltage Vs**2** to the source of the transistor **110**.

In FIG. **8**, b indicates a current characteristic of the transistor **110** in a case where the variable current sources **140** and **150** are provided. An alternate long and short dash line indicates a current driven by the transistor **110** in the case of a of FIG. **8** where the variable current sources **140** and **150** are not provided. In addition, a dotted line indicates a current driven by the variable current sources **140** and **150**. Thus, in the case where the variable current sources **140** and **150** are provided, these currents are added, and a current flowing through the transistor **110** is as indicated by a solid line.

A case where the input voltage Vin is applied to a positive side is considered. When a current of the transistor **110** increases, the source voltage Vs**1** increases. The variable current source **140** is set to start flowing a current when the source voltage Vs**1** exceeds a certain threshold. A linear region in which the transconductance gm is flat is increased by causing the current of the variable current source **140** to start flowing with the current saturation of the transistor **110**.

On the other hand, a case where the input voltage Vin is applied to a negative side is considered. When a current of the transistor **210** increases, the source voltage Vs**2** increases. The variable current source **150** is set to start flowing a current when the source voltage Vs**2** exceeds a certain threshold. A linear region in which the transconductance gm is flat is increased by causing the current of the variable current source **150** to start flowing with the current saturation of the transistor **110**.

Note that although the description has been given here by focusing on the current characteristics of the transistor **110**, the same applies to current characteristics of the transistor **210**.

As described above, in the second embodiment of the present technology, in the differential amplifier, the variable current sources **140** and **150** are connected to the source of the transistor **110** and the variable current sources **240** and **250** are connected to the source of the transistor **210**. With this configuration, it is possible to expand a region that is linearly driven without reducing gain.

3. Modification

[Circuit Configuration of Differential Amplifier]

FIG. **9** is a diagram illustrating a modification of the differential amplifier according to the second embodiment of the present technology.

Although the variable current sources **140**, **150**, **240**, and **250** are connected to the current source **190** in the above-described differential amplifier according to the second embodiment, they are grounded in this modification.

FIG. **10** is a diagram illustrating a first specific example of the variable current sources **140**, **150**, **240**, and **250** in the modification of the differential amplifier according to the second embodiment of the present technology.

The first specific example of this modification has a similar configuration to the above-described first specific example of the second embodiment, but is different in that the resistors **142** and **242** are grounded.

FIG. **11** is a diagram illustrating a second specific example of the variable current sources **140**, **150**, **240**, and **250** in the modification of the differential amplifier according to the second embodiment of the present technology.

The second specific example of this modification has a similar configuration to the above-described second specific example of the second embodiment. However, the second specific example of this modification is different in that the transistors **141**, **151**, **241**, and **251** and the bias voltage sources **145**, **155**, **245**, and **255** are grounded.

As described above, according to the embodiments of the present technology, it is possible to expand a region that is linearly driven without reducing gain in an amplifier circuit. With increase in communication capacity, the number of communication systems with a high peak-to-average power ratio (PAPR), such as long term evolution (LTE) and a TV tuner, is expected to increase. Since the increase in PAPR affects the maximum input sensitivity of a receiver, an amplifier with a wider dynamic range is required. In this embodiment, a region in which the transconductance gm is flat can be expanded without reducing gain, which contributes to lower power consumption of a highly linear receiver that requires high gain. Furthermore, the transistor inserted to improve linearity does not consume a direct current, but consumes a current only when a signal having a large amplitude is input, so that power consumption does not increase in a standby state or when a small signal is received, thereby contributing to lower power consumption of the receiver.

Note that the above-described embodiments indicate examples for embodying the present technology, and the matters in the embodiments and the matters specifying the invention in the claims have a correspondence relationship. Similarly, the matters specifying the invention in the claims and the matters having the same names in the embodiments of the present technology have a correspondence relationship. However, the present technology is not limited to the embodiments and can be embodied by making various modifications to the embodiments without departing from the gist of the present technology.

Note that the effects described in the present specification are merely examples and are not limitative, and other effects may be achieved.

Note that the present technology can also include the following configurations.

(1) An amplifier circuit including:

a transistor that amplifies an input signal;

a load connected between the transistor and a power supply;

an impedance element that is connected between the transistor and a ground terminal and passes a direct current; and

a variable current source that is connected to a connection part between the transistor and the impedance element and supplies a current in accordance with a voltage of the connection part.

(2) The amplifier circuit according to (1), in which

the transistor is a MOS transistor that amplifies the input signal input to a gate and outputs the amplified input signal to a drain,

the load is connected to the drain of the transistor,

the impedance element is connected to a source of the transistor, and

the variable current source supplies a current in accordance with a source voltage of the transistor to the source of the transistor.

(3) The amplifier circuit according to (1) or (2), in which

the variable current source includes:

an additional transistor having a gate and a drain connected to the connection part; and

a resistor connected between a source of the additional transistor and the ground terminal.

(4) The amplifier circuit according to (1) or (2), in which

the variable current source includes:

an additional transistor having a drain connected to the connection part;

a capacitor connected between the connection part and a gate of the additional transistor;

a resistor having one end connected to the gate of the additional transistor; and

a bias voltage source connected between another end of the resistor and the ground terminal.

(5) The amplifier circuit according to any one of (1) to (4), in which

the variable current source supplies the current in accordance with the voltage of the connection part in a region where a current supplied by the transistor starts to saturate relative to the input signal.

(6) The amplifier circuit according to any one of (1) to (5), in which

the impedance element is a resistance element.

(7) The amplifier circuit according to any one of (1) to (5), in which

the impedance element is an inductor element.

(8) The amplifier circuit according to any one of (1) to (7), in which

the load is a resistance element.

(9) An amplifier circuit including:

first and second transistors that amplify differential input signals;

first and second loads respectively connected between the first and second transistors and a power supply;

a current source having one end connected to a ground terminal;

first and second impedance elements that are respectively connected between the first and second transistors and another end of the current source and pass a direct current;

a first variable current source that has one end connected to a first connection part between the first transistor and the first impedance element and supplies a current in accordance with a voltage of the first connection part;

a second variable current source that has one end connected to a second connection part between the second transistor and the second impedance element and supplies a current in accordance with a voltage of the second connection part;

a third variable current source that has one end connected to the first connection part and supplies a current in accordance with the voltage of the second connection part; and

a fourth variable current source that has one end connected to the second connection part and supplies a current in accordance with the voltage of the first connection part.

(10) The amplifier circuit according to (9), in which

each of the first to fourth variable current sources has another end connected to the another end of the current source.

(11) The amplifier circuit according to (9) or (10), in which

each of the first to fourth variable current sources includes:

an additional transistor having a gate and a drain connected to the connection part; and

a resistor connected between a source of the additional transistor and the another end of the current source.

(12) The amplifier circuit according to (9) or (10), in which

each of the first to fourth variable current sources includes:

an additional transistor having a drain connected to the connection part;

a capacitor connected between the connection part and a gate of the additional transistor;

a resistor having one end connected to the gate of the additional transistor; and

a power supply connected between another end of the resistor and the another end of the current source.

(13) The amplifier circuit according to (9), in which

each of the first to fourth variable current sources has another end connected to the ground terminal.

(14) The amplifier circuit according to (9) or (13), in which

each of the first to fourth variable current sources includes:

an additional transistor having a gate and a drain connected to the connection part; and

a resistor connected between a source of the additional transistor and the ground terminal.

(15) The amplifier circuit according to (9) or (13), in which

each of the first to fourth variable current sources includes:

an additional transistor having a drain connected to the connection part;

a capacitor connected between the connection part and a gate of the additional transistor;

a resistor having one end connected to the gate of the additional transistor; and

a power supply connected between another end of the resistor and the ground terminal.

REFERENCE SIGNS LIST

110, **210** Transistor
120, **220** Load resistor
130, **230** Degeneration resistor
140, **150**, **240**, **250** Variable current source
141, **151**, **241**, **251** Transistor
142, **144**, **154**, **242**, **244**, **254** Resistor
143, **153**, **243**, **253** Capacitor
145, **155**, **245**, **255** Bias voltage source
190 Current source

The invention claimed is:

1. An amplifier circuit comprising:
a transistor that amplifies an input signal;
a load connected between the transistor and a power supply;
an impedance element that is connected between the transistor and a ground terminal and passes a direct current; and
a variable current source that is connected to a connection part between the transistor and the impedance element and supplies a current in accordance with a voltage of the connection part, the variable current source including:
an additional transistor having a drain connected to the connection part,
a capacitor connected between the connection part and a gate of the additional transistor,
a resistor having one end connected to the gate of the additional transistor, and
a bias voltage source connected between another end of the resistor and the ground terminal.

2. The amplifier circuit according to claim **1**, wherein
the variable current source supplies the current in accordance with the voltage of the connection part in a region where a current supplied by the transistor starts to saturate relative to the input signal.

3. The amplifier circuit according to claim **1**, wherein
the impedance element is a resistance element.

4. The amplifier circuit according to claim **1**, wherein
the impedance element is an inductor element.

5. The amplifier circuit according to claim **1**, wherein
the load is a resistance element.

6. An amplifier circuit comprising:
first and second transistors that amplify differential input signals;
first and second loads respectively connected between the first and second transistors and a power supply;
a current source having one end connected to a ground terminal;
first and second impedance elements that are respectively connected between the first and second transistors and another end of the current source and pass a direct current;
a first variable current source that has one end connected to a first connection part between the first transistor and the first impedance element and supplies a current in accordance with a voltage of the first connection part;
a second variable current source that has one end connected to a second connection part between the second transistor and the second impedance element and supplies a current in accordance with a voltage of the second connection part;
a third variable current source that has one end connected to the first connection part and supplies a current in accordance with the voltage of the second connection part; and
a fourth variable current source that has one end connected to the second connection part and supplies a current in accordance with the voltage of the first connection part, wherein
each of the first to fourth variable current sources has another end connected to the another end of the current source.

7. The amplifier circuit according to claim **6**, wherein
each of the first to fourth variable current sources includes:
an additional transistor having a gate and a drain connected to the connection part; and
a resistor connected between a source of the additional transistor and the another end of the current source.

8. The amplifier circuit according to claim **6**, wherein
each of the first to fourth variable current sources includes:
an additional transistor having a drain connected to the connection part;
a capacitor connected between the connection part and a gate of the additional transistor;
a resistor having one end, connected to the gate of the additional transistor; and
a power supply connected between another end of the resistor and the another end of the current source.

9. The amplifier circuit according to claim **6**, wherein
each of the first to fourth variable current sources has the another end connected to the ground terminal.

10. The amplifier circuit according to claim 6, wherein each of the first to fourth variable current sources includes:

an additional transistor having a gate and a drain connected to the connection part; and

a resistor connected between a source of the additional transistor and the ground terminal.

11. The amplifier circuit according to claim 6, wherein each of the first to fourth variable current sources includes:

an additional transistor having a drain connected to the connection part;

a capacitor connected between the connection part and a gate of the additional transistor;

a resistor having one end connected to the gate of the additional transistor; and

a power supply connected between another end of the resistor and the ground terminal.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 11,368,129 B2
APPLICATION NO. : 17/052373
DATED : June 21, 2022
INVENTOR(S) : Yoshikatsu Jingu

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

On the Title Page

Item (30) FOREIGN APPLICATION PRIORITY DATA:
Please add "May 10, 2019 (JP)……..JP2018-091643,"

Signed and Sealed this
Eighteenth Day of October, 2022

Katherine Kelly Vidal

Katherine Kelly Vidal
Director of the United States Patent and Trademark Office